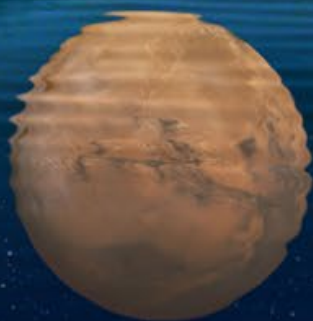




# EXPLORE MOON<sub>to</sub>MARS

MOON LIGHTS THE WAY





# Advancements in Logistics Reduction for Exploration Missions

ICES-2023-040

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# Introduction

- **Logistics Reduction is about....**
  - **TECHNOLOGIES** for reducing crew consumable mass, reducing crew time for logistics management, and managing trash
  - **...Reducing mass, volume, and crew time**
  - and addressing exploration technology gaps using a range of government and industry collaborations to enable the space economy.
- **This means...**
  - Compact toilets, optimization of fecal canisters mass and volume, trash management strategies, autonomous tracking of cargo, autonomous manipulation of cargo using robotics, and longer wear crew clothing

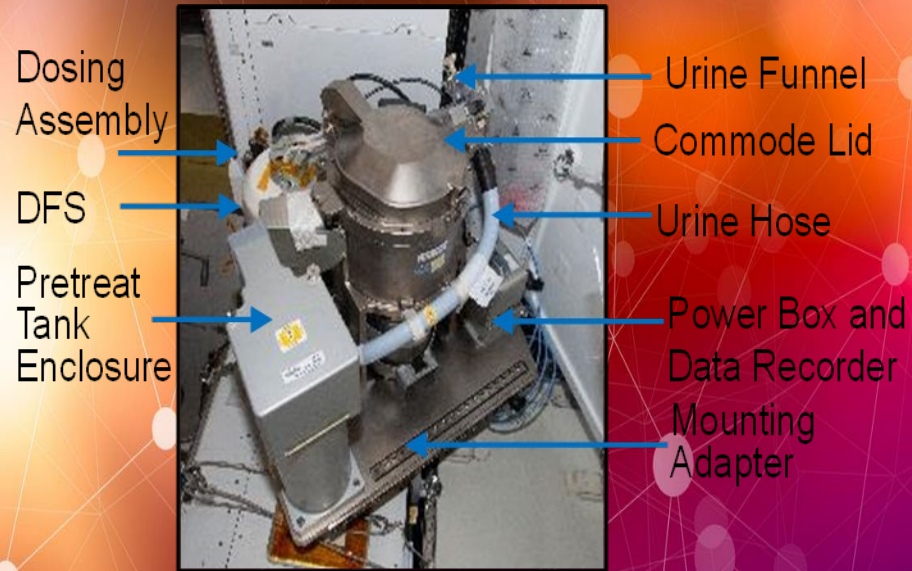
| LR Technologies                                             | Mass Reduction Approach |             |                             |              |                                |                       |                         | LR Goals FY22+               |                |                |               |                  |                     |               |
|-------------------------------------------------------------|-------------------------|-------------|-----------------------------|--------------|--------------------------------|-----------------------|-------------------------|------------------------------|----------------|----------------|---------------|------------------|---------------------|---------------|
|                                                             | Direct Mass Reduction   | Reduces ESM | Improved Logistics Tracking | Direct Reuse | Processing for Second Function | Deconstruction to Gas | Autonomy and Automation | ISS TD in FY22               | ISS TD in FY23 | ISS TD in FY24 | MPCV Infusion | Gateway Infusion | Mars/Junar Infusion | SBIR Infusion |
| Universal Waste Management System (UWMS)                    | Y                       | Y           |                             |              |                                |                       |                         | Y                            |                |                |               | Y                | Y                   |               |
| UWMS Alt Fecal Container                                    | Y                       | Y           |                             |              | Y                              |                       |                         | Y                            |                |                |               | Y                | Y                   |               |
| UWMS Pretreat Tank                                          | M                       | M           |                             |              |                                |                       |                         |                              |                | Y              |               | Y                | Y                   |               |
| RRID Enabled Autonomous Logistics - Fixed Readers (REALM 1) |                         | Y           | Y                           |              |                                |                       | Y                       | Transition to ISS sustaining |                |                |               | Y                | Y                   |               |
| REALM - Mobile Reader (REALM 2)                             |                         | Y           | Y                           |              |                                |                       | Y                       | Y                            | Y              |                |               | Y                | Y                   |               |
| REALM - Dense Zone Reader (REALM 3)                         |                         | Y           | Y                           |              |                                |                       | Y                       | Y                            |                |                |               | Y                | Y                   |               |
| REALM - 6 Degree of Freedom (REALM 6DOF)                    |                         | Y           | Y                           |              |                                |                       | Y                       |                              | Y              |                |               | Y                | Y                   | III           |
| RRID Sensors                                                |                         | Y           | Y                           |              |                                |                       | Y                       |                              | Y              |                |               | Y                | Y                   | III           |
| Trash Compactor Processing System (TCPS)                    | Y                       |             |                             |              | Y                              |                       |                         |                              |                | Y              |               | M                | Y                   | IE            |
| Autonomous Logistics (AL)                                   |                         |             | Y                           |              |                                |                       | Y                       |                              |                |                |               | Y                | Y                   |               |
| Advanced Clothing Systems (ACS) - Long Wear Clothing        | Y                       | Y           |                             |              |                                |                       | M                       |                              | M              | M              | M             | Y                | Y                   |               |
| ACS - Laundry                                               |                         | M           |                             | Y            |                                |                       |                         | Y                            | Y              |                |               |                  | M                   | IE            |
| Multipurpose Cargo Transfer Bags (MCTBs)                    |                         | Y           |                             | Y            |                                |                       |                         |                              |                | M              |               | M                | M                   |               |
| Fecal Processing                                            | Y                       | Y           |                             |              | Y                              |                       |                         |                              |                |                |               | M                | M                   | I & IE        |
| Trash to Gas (TtG) - venting/jettison                       |                         | M           |                             |              |                                | Y                     |                         |                              |                | Y              |               | M                | M                   | II            |
| SE&I-Long Term Waste & Food Storage                         | M                       | M           |                             |              | M                              | M                     |                         |                              |                | M              |               | M                | M                   | IE            |
| In-Space Manufacturing                                      | Y                       | Y           |                             |              | Y                              |                       |                         | Y                            | Y              | Y              |               | Y                |                     |               |

Legend: Y = Yes or Applicable  
M = Maybe or Depends on Mission Assumptions  
I, II, III or IE = SBIR phase

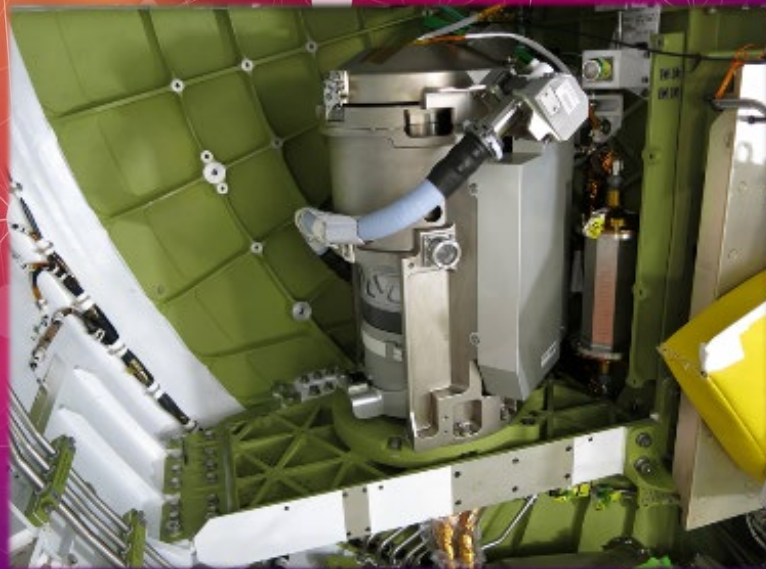
## • WHY?

- Less mass and volume directly assist in spacecraft design
- Reductions in logistics-related crew time frees up time for science, vehicle critical activities and ....





ISS UWMS installed in Node 3, ISS



Orion UWMS installed in Artemis-II

# Metabolic Waste – UWMS (Toilet)

- Universal Waste Management System
  - ISS Unit – Toilet
  - Orion Unit – Waste Management System (WMS)
- Toilet for exploration missions
- Reduction in mass and volume
  - Toilet is 65% smaller and 40% lighter than current ISS toilet (WHC)
  - WMS is 61% smaller than Shuttle Toilet
- ISS Toilet
  - Delivered June 2020
  - Completed 17-day Limited Checkout in November 2021
    - *Returned Fecal Canister updated capacity from 20 to 13 deposits which is a key manifest item for Orion's Artemis-2+*
  - *Currently working technical challenges*
- Orion WMS
  - Delivered December 2019
  - Installed into Artemis-II Vehicle March 2021
  - Powered/run every 3 months since delivery and install
  - Awaiting launch of Artemis-II



# Metabolic Waste – Alternate Fecal Canister (AFC)

- ISS toilets use hard-sided metal canisters to collect and store feces
  - Heavy
  - Empty canisters take up a lot of room for launch and stowage
  - Robust and efficient for containing waste and odors
- Alternate Fecal Canister (AFC) developed for use with UWMS (ISS new Toilet) and compresses for launch/stowage when empty
  - Volume savings
  - Weight savings
  - Use of flexible material and construction equally efficient at containing waste and odors
    - Material selection key to successful design
    - Commercial Body Bag material
- Currently first set of AFC's are on ISS awaiting technology demonstration with UWMS

| Volume Comparison (cm <sup>3</sup> ) |                      |         |
|--------------------------------------|----------------------|---------|
|                                      | Empty and Compressed | Full    |
| AFC                                  | 1250                 | 8193    |
| UWMS FC                              | 13517                | 13517   |
| Mass Comparison (kg)                 |                      |         |
|                                      | W/ Lid*              | W/o Lid |
| AFC                                  | 1.131                | 0.451   |
| UWMS FC                              | 1.5                  | 0.82    |

\*Lid Mass 0.68kg

Volume and mass comparison for fecal canisters

# Other Metabolic Waste Advancements

- Pursuing SBIR contracts for fecal processing for water recovery and stabilization of waste
  - Advanced Fuel Research – Torrefaction of feces at temperatures up to 250°C
  - Ultrasonic Technology Solutions – Using piezoelectric transducers to mechanically shake water out of feces with ultrasonic waves
- Updated Seat and Fecal Bag design – redesign in progress starting with HLS Lavatory On-Orbit (LOO) design
  - Demonstration planned with UWMS on ISS
  - Will potentially replace bags/seat on Orion's Artemis-2



# ISS Inventory and Stowage and REALM Experiments

- ISS has approx. 118 cu m (2250 CTBe) of usable stowage space
  - CTBe: Cargo Transfer Bag equivalent
- On board stowage is tracked and utilized via the Inventory Management System (IMS)
  - Tracks over 130,000 items (2019)
    - 64,000 items are active
    - ~3,000 items are considered lost
- **RFID-Enabled Autonomous Logistics Management (REALM)** experiments are jointly funded by NASA's Advanced Exploration Systems (AES) and ISS Programs
- Why: Autonomous Logistics Management (ALM) was identified in 2015 as a high priority technology need for long duration Human Exploration missions
  - Identify location of all items
  - Allows for more efficient packing
- Objectives:
  - Use ISS to learn how to implement Autonomous Logistics Management
  - Determine combinations of RFID strategies and how they might vary according to mission needs
  - Apply knowledge to define a REALM system for Artemis and other remote exploration missions

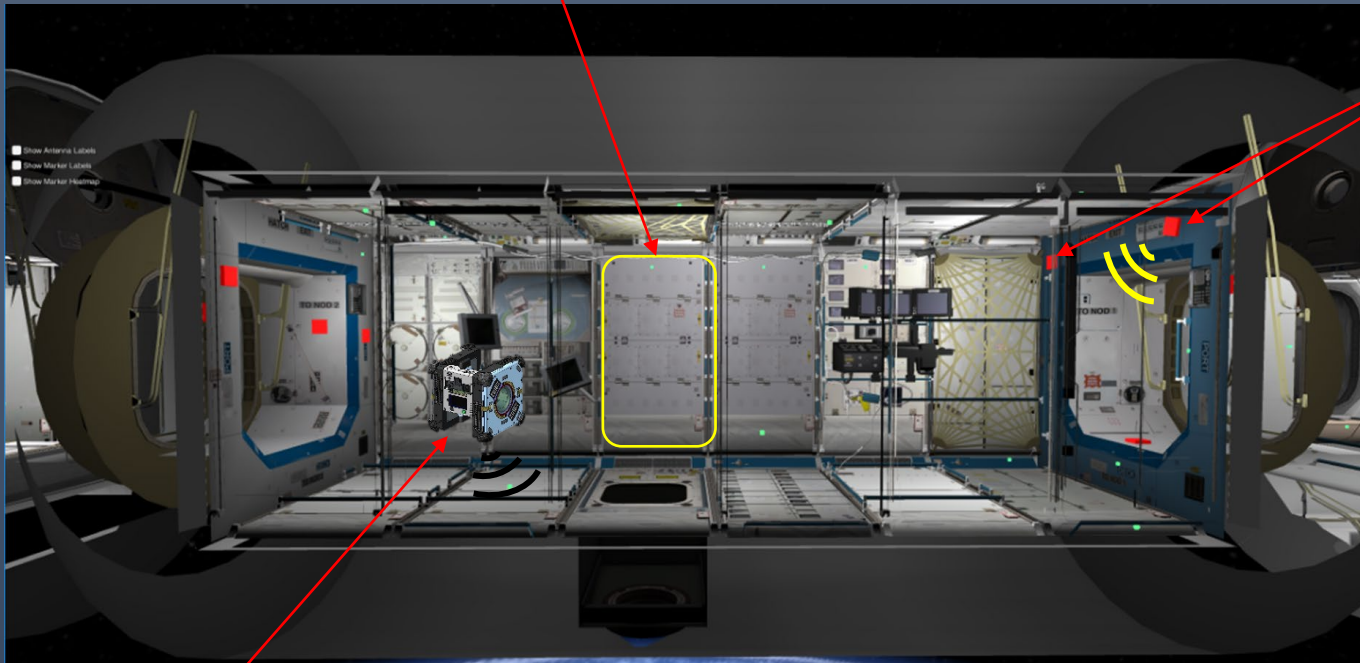


# REALM RFID Technology Building Blocks

## REALM-3

- Smart stowage system (reader integrated into drawers/racks)

**Key attribute:** RF penetration into dense collections



## REALM-2

- Robotic free-flyer equipped with RFID reader

**Key attribute:** mobile, coverage extension, homing

## REALM-1

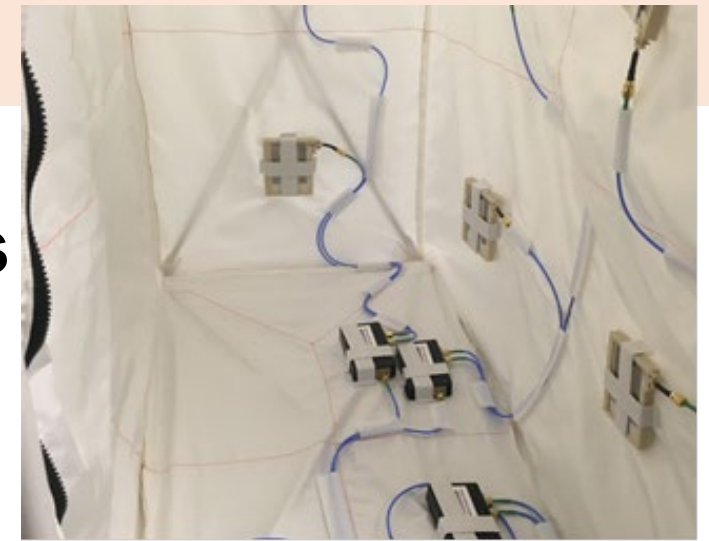
- Fixed reader/antenna System

**Key attribute:** pervasive, 24/7 coverage



Flight-like prototype Smart Stow in a mockup

# Autonomous Logistics Management – REALM-3



Embedded antenna system called HYDRA (HYper-Distributed RFID Antenna)

## What is it....

- **REALM-3:** RFID reader antennas integrated within stowage racks or behind rack faces to decrease the amount of tags that are obscured from the REALM-1 system, and to improve the localization accuracy. REALM-3 directly builds on REALM-1.
- **Smart Stow:**
  - Specific ISS implementation with embedded antennas
  - Comprises 4 textile quadrants that fit into existing compartments of a textile ISS ZSR (zero-gravity stowage rack).
- **HYDRA:** Each quadrant of Smart Stow has an embedded antenna system called HYDRA (HYper-Distributed RFID Antenna),
  - HYDRA is a switched multiplexer antenna system that connects to an RF port of a reader and powers itself by harvesting a small fraction of the incident RFID signal to run an internal microcontroller and switch.
  - Each HYDRA node can connect to other HYDRA nodes or to antennas, all of which are switched so that only one antenna is active at any time.
  - In the combined four quadrants of Smart Stow, HYDRA contains 24 antennas, the same as the entire REALM-1 constellation in 3 ISS modules

## Status....

- **REALM-3 Smart Stow:**
  - REALM-3 Smart Stow was commissioned on ISS in Q1 of FY23
  - already demonstrated a greatly improved capability to read items missed by the REALM-1 system and to locate items more accurately, data analysis is in work to determine the quantitative impacts.
- **HYDRA:**
  - Under development
  - Evaluating numerous variations on previous HYDRA antenna for greater resilience on background materials, especially ground plane size to better accommodate Artemis mounting locations.

# Autonomous Logistics Management – REALM-2

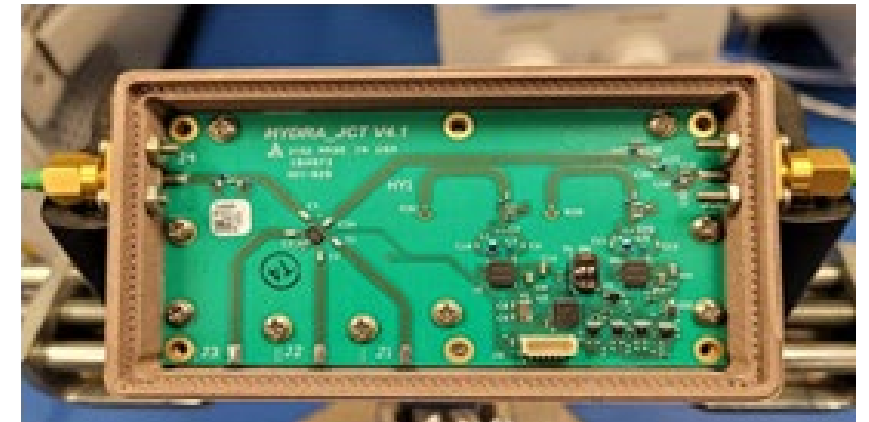
- REALM-2: RFID payload, including a reader and antennas, on a robotic free-flyer called Astrobees.
- Operating on ISS since 2020
- Conducts inventory audits and can hone in on single targeted tags within about 8 inches
- Since the Permanent Multi-purpose Module (PMM) is not instrumented and is not adjacent to an instrumented module, the REALM-1 system is unable to detect the majority of tagged items in the PMM.
- During this REALM-2 mission, the combined tags seen by REALM-1 and REALM-2 reached 2,021 of a reported 2,819 total RFID tags on ISS at the time. In contrast, REALM-1, alone, only read 1,404 of these tags.



# InSpace Manufacturing (ISM)

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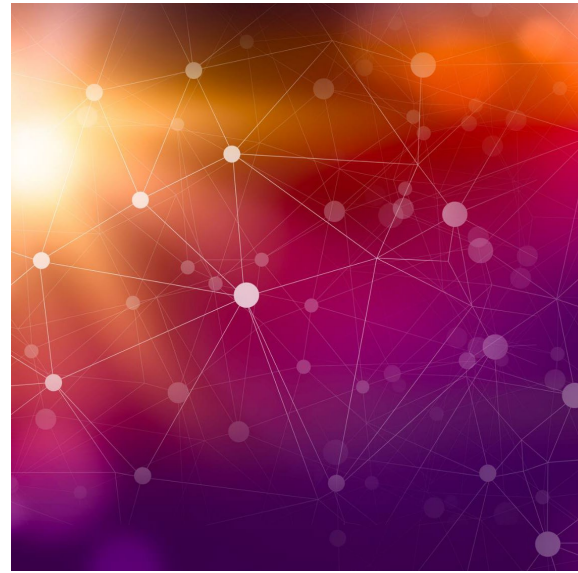
- Synergy with manufacturing of REALM antennas and housing
- The REALM-2 flight housing is additive manufactured
- Titanium RFID antenna bases
  - Replace bulky polymer/metal composite bases used in the past.
  - Much lighter and stiffer as antenna bases
  - Significant weight reductions
  - Potential expansion of the REALM system with additional nodes for performance enhancement



HYDRA PCB in ISM 3D-printed housing.  
Weight: 56% of Aluminum housing, RF  
loss: 2.25 dB, 1.8 dB for AL

# Trash Management – Trash Compaction and Processing System (TCPS)

- Waste management technology to reduce trash volume
  - Reduce risk of biological activity in trash
  - Stabilize trash for efficient storage
  - Water recovery and manage gaseous effluents
- Contract awarded to Sierra Nevada Corp (in August 2022) to develop TCPS for an ISS flight demonstration
  - Source Contaminant Control System (NASA's risk reduction activities)
    - Determine gaseous effluents from TCPS to characterize system efficiency
    - Characterize particulate matter released during TCPS ops (particulate size, density and morphology)
- Other Trash Management Efforts
  - Planetary Protection → Policy applicable to trash mgt; contain all waste to prevent microbial release if waste is left on planet's surface
  - Jettison → Option for discarding processed trash; study for a launching system that can handle different waste types (size/shapes)
  - Waste to Base → Develop low TRL solutions for trash mgt, CO<sub>2</sub> processing, foam re-processing, and fecal processing
  - Manual Trash Compactor → Design a manual compactor for use during transit or on planetary surface (low power, mass and volume)



TCPS loaded with trash for testing  
(at ARC)



TCPS and Particulate  
Measurement System

SCCS/CatOX  
Gas Reactor

GasMet  
Measurement  
System

# Trash Management- Trash to Gas

- Trash to Gas: Solid trash deconstruction using thermal degradation
  - Mass and volume reduction
  - Potential to recover resources in the form of propellant or other ECLSS commodities.
    - Recovering water from the trash is highly desirable,
    - Residual dry trash has properties that can be utilized to
      - Convert to useful gases for fuel or commodity use,
      - Solids that will contain carbonaceous ash with crop nutrients and metals. The processed residual trash must be in a stable physical form and biologically inert for long-term storage.
- Orbital Syngas/Commodity Augmentation Reactor (OSCAR)-Full Scale ground system is in design phase - 4-crew Trash to Gas/Trash Venting System for 6.7kg/day trash processing. Larger throughput than OSCAR suborbital test unit.
- SBIR Phase III with Pioneer Astronautics: Advanced Organic Waste Gasifier (AOWG) - full scale trash gasification and venting system has been successfully ground tested, tested TCPS tiles
- SBIR Ignite Ph1 Kicked off 1/2023: "Point-of-Use Recycling for Optimized Space-Age Logistics." Cecilia Energy: Catalytic Conversion of Waste Plastic to Hydrogen.
- IAA with NASA KSC/Air Force established 2/2023 – Developing microwave plasma system for high throughput waste processing.



OSCAR Reactor with ~22grams of shredded TCPS tiles



Subscale Trash to Gas OSCAR reactor



# ACS – Advanced Clothing System

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- Clothing represents about 25% of an astronaut's crew provisions (excluding food)
- There are no current washer/dryers certified for space
- Through a Space Act Agreement with Procter and Gamble (P&G), researchers developed Tide Infinity™ detergent to meet the constraints of being fully degradable and compatible with closed loop air and water systems
  - Testing planned in the Crew Health And Performance Exploration Analog (CHAPEA) at JSC starting this summer
- In-situ hydrogen peroxide generator being developed by the ACS team in collaboration with the EC Life Support project's air team and small business partner Faraday Technologies
- Clothing for ISS is certified to meet flammability requirements up to 30% O<sub>2</sub> at 10.2psia, but capability up to 36% O<sub>2</sub> at 8.3 psia is desired for exploration missions
  - Several SBIR and STTR contracts are underway looking into fire retardant treatments as well as fundamentally lower flammability fibers

## Design of a Jettison System For Space Transit Vehicles

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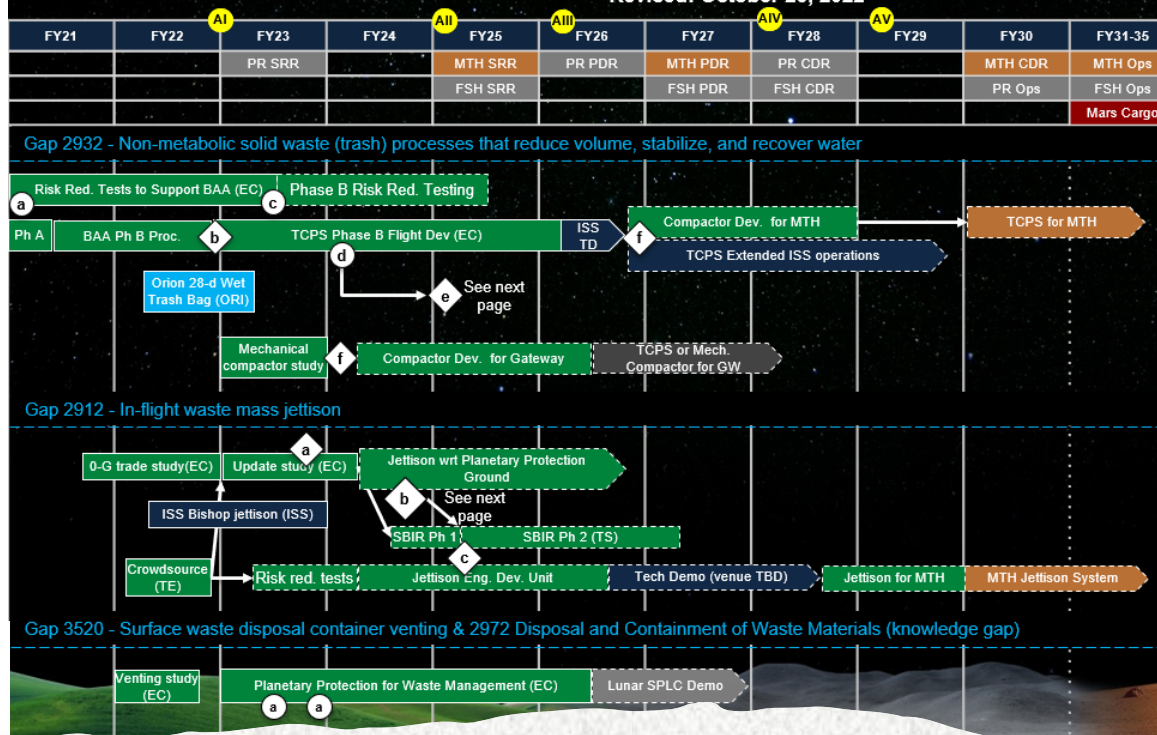
Chandranath Venigalla<sup>4</sup>  
University of Colorado, USA

and

Jeffrey Lee<sup>5</sup>  
NASA Ames Research Center, USA

Many options to re-use waste are currently being developed by NASA. These include combustion, compaction, torrefaction, and converting waste materials to an easily stored base polymer for future use. Human exploration missions require large amounts of supplies such as food, clothing and spare parts. A many-month journey to Mars will still result in the generation of a substantial amount of problematic waste products. It is thought that this waste must be discarded to enable a Mars transit mission. The most cost-effective, reliable, and safest method to address this problem may be to simply jettison these materials from the spacecraft. The ability to jettison requires a multi-component integrated system design. Major components include a launcher, airlock, trash bags, and tracking system. Depending upon mission requirements, a jettison dedicated airlock may be necessary. In other cases, the crew airlock might be all that is needed. This paper will discuss these design issues and give guidance to a pathway forward.

# SE&I – Systems Engineering & Integration



## Session 304E – Thur.

### Benefits of Trash-to-Gas versus Jettison of Waste via Trash-Lock for Mars Transit

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Human exploration missions to Mars pose difficulties due to the significant waste that will be generated during transit, which will need to be carried along or disposed of in some fashion. Waste removal from the spacecraft decreases the spacecraft's mass as well as the associated logistic items necessary for storing the waste. A mission propellant analysis was performed to highlight the mass benefits that may be accessed via waste removal. The propellant mass savings were determined for different waste removal rates (2.9 – 11.6 kg/day) with the highest removal rate leading to the greatest propellant savings of 7,785 kg for an 850-day round-trip mission. Due to these benefits, two methods for waste reduction were studied for the 850-day Mars mission: Trash-to-Gas (TiG) and physical jettison via a trash-lock. The trash-to-gas methods considered were combustion, steam reforming, and pyrolysis, which convert waste into ventable gases (e.g., CO<sub>2</sub>, CO, CH<sub>4</sub>, etc.). Combustion and steam reforming require a co-reactant (O<sub>2</sub> and/or H<sub>2</sub>O). Therefore, additional processing units or integration with the spacecraft's environmental control and life support system (ECLSS) are required to facilitate recycle of the pertinent species. In contrast, pyrolysis is a purely thermal degradation process, which can operate as a standalone system; however, a lower percentage of waste is gasified with pyrolysis. The study herein compares standalone TiG (e.g., Advanced Organic Waste Gasifier, Plasma Pyrolysis, etc.), integrated TiG-ECLSS (e.g., Orbital Syngas Commodity Augmentation Reactor, Incineration/Gasification, etc.), and physical jettison. Each system's mass, volume, power, and cooling requirements were compared via an equivalent system mass (ESM) analysis to ascertain potentially promising technologies that can achieve efficient waste removal while minimizing their own spacecraft load. This study highlights the advantages and disadvantages of the different waste management technologies and provides recommendations on the promising technologies based on the ESM metric and propellant mass savings.

- SE&I helps other LR elements optimize and fit into the big picture (e.g., roadmaps)
- Some high energy missions such as Mars Transit have a very strong driver to get rid of waste during the mission to reduce vehicle mass and thus propellant use. SE&I trade studies include:
  - Jettison optimization (ICES 2022)
  - Trash-to-gas technology vs. physical jettison (ICES 2023)

# Conclusion



- *Logistics Reduction:*
  - **Helps improve current programs**
  - **Prepares for Moon and Mars Missions**
  - **Informs decisions on hardware and operational strategies**



## Questions or Feedback?

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- *Melissa K. McKinley*
  - ***Exploration Capabilities  
Logistics Reduction Project  
Manager***